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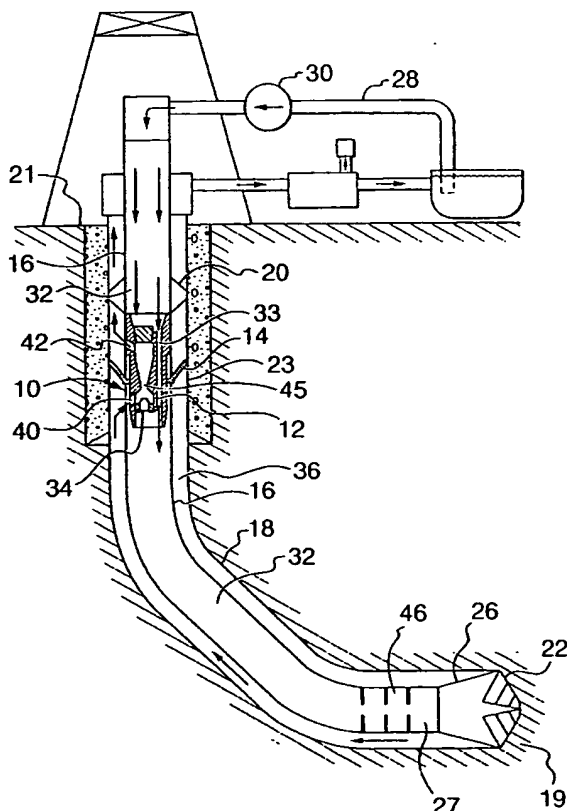
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(54) Title: UNDERBALANCED DRILLING TOOL AND METHOD



(57) Abstract: A pressure differential drilling tool is described for reducing pressure in the annulus between a drill string and a wellbore in a drilling zone. The pressure differential drilling tool includes (a) a jet pump including a power nozzle having a nozzle inlet, a pump inlet, a pump outlet and a drilling fluid conduit extending between the pump inlet and the pump outlet and in communication with the power nozzle, the jet pump being connectable into the drill string such that the nozzle inlet is accessible from the drill string inner bore and the pump inlet and the pump outlet open into the annulus (b) a bypass port for fluid through the drill string inner bore and bypass around the jet pump and (c) the wellbore pack off seal positioned about the jet pump between the pump inlet and the pump outlet and operable to create a seal preventing fluid communication between the pump inlet and the pump outlet except through the fluid conduit and being moveable with the jet pump, while in operation, through the wellbore.

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## UNDERBALANCED DRILLING TOOL AND METHOD

### FIELD OF INVENTION

This invention relates to drilling devices and processes used in the drilling of underground wellbores. More specifically, the invention is concerned with the control of fluid pressure  
5 within a wellbore during the process of drilling a wellbore.

### BACKGROUND OF THE INVENTION

During the process of "rotary" drilling a wellbore into an underground rock formation, drilling fluid is circulated through the drill string and the drill bit to lubricate, cool and clean the rotating drill bit. The drilling fluid also erodes the rock surface and flushes drilled  
10 cuttings to surface. Commonly, when drilling through formations containing moveable oil, gas or water, the drilling fluid is a water-based or oil-based liquid containing specific soluble and insoluble compounds and materials. Such drilling fluids are normally of high enough density that the pressure of the fluid column from the depth of the formation to surface is higher than the pressure of the fluid in the underground formation and this condition is called  
15 pressure "overbalance". The advantage of "overbalance" is to prevent excessive flow of formation fluids into the wellbore, wherein the excessive flow could lead to a blowout situation wherein unmanageable and dangerous amounts of formation fluid are released at surface while drilling.

20 The disadvantages of overbalance condition are, first, that drilling fluids are pressured into the formation which impairs the flow capability of the completed wellbore; and, second, that the drilling rate is reduced, which increases well cost.

In many situations, wells are drilled with pressure "underbalance" to counteract the  
25 disadvantages of overbalance drilling. Underbalanced drilling is typically accomplished by using a fluid with lower density than water or oil-based liquid to reduce the pressure of the fluid column. Compressed air is used as a drilling fluid in some dry or dry gas wellbores but has the disadvantage of fire/explosion risk and corrosion of the drill string. The use of compressed hydrocarbon gas rather than air will remove the corrosion and downhole

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- fire/explosion risks but surface fire/explosion risks remain. Compressed inert gas, such as nitrogen, offsets the fire/explosion risks and reduces corrosion but is more costly because the gas must be either purchased or generated on site. Also the use of inert gas can result in release of unburned hydrocarbon and toxic formation gases into the surface environment.
- 5 Reduction of fluid column pressure is also achieved by compressing gases into liquid-based drilling fluids to create misted, foamed or gasified fluids. These drilling fluids are used commonly where liquids are produced by the formation.

- The use of compressed gases has multiple disadvantages. Data from conventional pressure pulse downhole data telemetry devices, referred to as monitoring while drilling (MWD) or logging while drilling (LWD) tools, is lost due to the inability to transmit and receive adequate pressure pulses through highly compressible fluids. Vibrations created by multiphase fluid through downhole devices cause damage to the downhole data sensors and transmitters. While connecting or disconnecting drill string components, the compressed
- 10 fluids in the drill string must be allowed to vent. Backflow prevention devices installed in the drill string, will usually eliminate the use of electronic data transmission cables. Rapid decompression of gases through the drill bit and downhole fluid-powered drilling-motors results in damage to those components and also leads to local cooling at the formation face which may result in precipitation of paraffin or other plugging solids. The combination of
- 15 erosive fluid velocities, irregular pressure cycles and very low backpressure on the wellbore walls often results in instability of the wellbore walls or collapse thereof. The use of compressed gas in combination with liquids creates a technical challenge in accurately estimating fluid column pressure, and as a result, the condition of pressure underbalance is sometimes not achieved.

- 25 Prior art for underbalanced drilling also includes the use of parasite pipe and concentric casing flow paths to enable continuous injection of compressed gas in the upper portion of the return circulation flow path at a sufficient depth that the reduced fluid column pressure creates a condition of pressure underbalance. The additional disadvantage of using
- 30 compressed gas in this system is the expense of installing the extra flow paths.

The decompression of large volumes of gas within the circulated fluids returning to surface creates a hostile environment that must be controlled and monitored within large multiphase

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pressure vessels. Highly gasified compression and control lines contain high energy and are very dangerous when ruptured accidentally or by erosion/corrosion. Self-energizing elastomer seals are installed at the wellhead to divert return wellbore flow for low pressure underbalanced drilling operations. Energized blow out preventers or extra bag type blow out preventers are installed at the wellhead to divert flow for higher pressure and toxic gas operations.

Prior art for underbalanced drilling also includes the use of hollow microspheres that are lower in density than water. The method has been field tested and disadvantages include the cost of the material, loss of the material through solids disposal equipment normally used in rotary drilling, and a tendency to float. The method is applied more to zero underbalance drilling, often referred to as "on balance drilling".

Although underbalanced drilling is common, any decrease in the pressure overbalance created by a full column of drilling fluid will create an increase in drilling penetration rates. Therefore, any of the methods used for reduction of fluid column pressure may be used to increase drill rate alone without necessarily creating a condition of pressure underbalance.

Jet pumps have been patented to set up pressure differentials along the wellbore. In particular, jet pumps have been patented for annular restriction devices to create reduced pressure at the bit.

One such jet pump configuration is disclosed in U.S. Patent no. 4,534,426 of Hooper. This patent discloses a "Big Hole" shaft drilling method for creating boreholes of very large diameter. Big Hole drilling is used in construction applications for drilling of shafts of diameter from 36 inches to 180 inches. Big Holes are drilled using cutting structures on frames which differ dramatically from conventional drill bits which are useful for drilling holes of up to 26 inches in diameter. The patent describes the use of dual walled drill pipe and the drilling fluid does not flow to the surface through the casing annulus. This is fundamentally different than conventional drilling which uses simple single walled pipe.

Another prior art jet pump device is disclosed in U.S. Patent no. 4,630,691. While a jet pump is used to create a pressure differential, the assembly as described in the patent does not

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provide adequate control and maintenance of the fluid pressure differential in the wellbore, thereby, reducing the effectiveness of the assembly in any underbalanced drilling operation.

## SUMMARY OF THE INVENTION

5 When drilling an underground wellbore, reducing the pressure of the circulated drilling fluid is of advantage and the technique of underbalanced drilling is frequently applied. Many of the recognized disadvantages with respect to the use of compressed gas in underbalanced drilling can be alleviated or eliminated by use of the pressure differential drilling tool of the present invention in place of the gas system. The tool of the present invention reduces the circulating pressure at the bottom of the wellbore by using the energy of the drill fluid.

10 The pressure differential drilling tool is mounted in the drill string and includes a jet pump and a wellbore packoff seal. The wellbore pack off seal, commonly referred to as a "packer", maintains a seal in the annulus between the drill string and the wellbore, or wellbore casing pipe if the well is cased, (herein referred to as the wellbore) during the drilling process. The packer prevents drilling fluid from passing therepast in at least a selected direction through  
15 the annulus, while being moveable along the wellbore. The jet pump draws the drilling fluid from the annulus below the packer, forces it through a flow path through the tool of the present invention and injects the drilling fluid back into the annulus above the packer. This creates an underbalanced condition in the annulus below the packer (toward the bit), referred to herein as the lower annulus, wherein the fluid pressure in the lower annulus between the  
20 drill bit and the packer is reduced relative to that fluid pressure in the drill string and in the annulus on the uphole side of the packer, referred to herein as the upper annulus.

Thus, in accordance with a broad aspect of the present invention, there is provided a pressure differential drilling tool for reducing pressure in the annulus between a drill string and a wellbore in a drilling zone, the pressure differential drilling tool comprising: (a) a jet pump  
25 including a power nozzle having a nozzle inlet, a pump inlet, a pump outlet and a drilling fluid conduit, including a throat and a diffuser, extending between the pump inlet and the pump outlet and in communication with the power nozzle, the jet pump being connectable into the drill string such that the power nozzle inlet is open to a power fluid flow path providing a source of power fluid to the power nozzle to drive the jet pump and the pump  
30 inlet is open to a fluid return flow path from below the jet pump, the jet pump being driveable to reduce the pressure of fluid in the return flow path (b) a bypass port for fluid flow

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downwardly and around the jet pump and (c) a wellbore pack off seal positioned about the jet pump and operable to create a seal in the annulus preventing fluid communication between a high pressure region in the annulus and a low pressure region in the annulus and being moveable with the jet pump, while in operation, through the wellbore.

- 5 In accordance with another aspect of the present invention, there is provided pressure differential drilling assembly for reducing fluid pressure in an annulus between a drill string and a wellbore in a drilling zone, the drill string including an inner bore for conducting drilling fluid therethrough, the pressure differential drilling assembly comprising: a drill bit for removing formation cuttings from the bore bottom and connected at a distal end of the
- 10 drill string; a wellbore pack off seal for creating a seal against drilling fluid flow therepast through the annulus about the drill string and defining a lower annulus therebelow and an upper annulus thereabove; a jet pump connected into the drill string and including a power nozzle, a throat, a diffuser, a pump inlet opening between the power nozzle and the throat and a pump outlet past the diffuser, the power nozzle having an nozzle inlet open to a power fluid
- 15 flow path for providing a source of power fluid to the power nozzle to drive the jet pump and the pump inlet being open to a fluid return flow path in pressure communication with the lower annulus, the jet pump being operable to reduce the fluid pressure in the return flow path; and a bypass port for fluid flow toward the drill bit and around the jet pump.

Extra drilling fluid, in excess of that needed to drive or flush the drill bit, is added at surface

20 and the extra fluid is diverted through the power nozzle of the jet pump which is mounted in the drill string in the vicinity of the packer. The venturi action created by sufficiently high flow rates through an appropriately sized jet pump will create suction at the pump inlet. The pump inlet is located below the packer such that the jet pump draws fluid from the drilling fluid down stream of the drill bit. This reduces the pressure of the fluid column downstream

25 of the bit and thereby creates a region of low pressure in the annulus between the packer and the bit. The suction fluid, along with the entrained drill cuttings and any formation fluid influx in response to the pressure underbalance condition, is discharged from the pump via the outlet port located above the packer at sufficient pressure to flow into the surface fluid control system.

- 30 The tool of the present invention can accommodate various circulation paths. In particular, drilling fluid can be pumped from surface through the drill string bore or through the annulus. Return fluid from the bit can also flow either through the drill string bore or through the

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annulus.

The packer and the jet pump energy prevent the pressure of the fluid column above the packer from exerting full pressure on the fluid below the packer. By locating the jet pump device at sufficient depth in the drill string, it is possible to achieve the required degree of pressure underbalance or reduced pressure overbalance at the drillface and open wellbore adjacent the drill face.

One embodiment of the present invention includes flow pressure and/or rate control devices to ensure that proper flow diversion occurs through the jet pump. The tool of the present invention can include at least one check valve to control fluid flow direction and ensure that underbalanced conditions are maintained when drilling fluid circulation is stopped. The packer must maintain its seal while the drill bit is advancing and during all other operations where it is desirable to maintain reduced pressure in the annulus below the packer.

To facilitate repair and other handling, the jet pump portion of the tool can be made to be retrievable from its operational position along the drill string. In particular, the drill string can carry the packer while a body carrying the jet pump is latchable in the drill string and can be retrieved therethrough.

In accordance with another broad aspect of the present invention, there is provided a process for drilling a wellbore through an underground formation and creating a reduced fluid pressure in an annulus between the drill string and the wellbore in the drilling zone, the process comprising: providing a drill string including an inner bore for conducting drilling fluid therethrough; providing a drill bit for removing formation cuttings at the drill face, the drill bit connected at a distal end of the drill string; providing a pressure differential drilling assembly including a wellbore pack off seal for creating a seal against drilling fluid flow therepast through the annulus about the drill string and defining a lower annulus therebelow and an upper annulus thereabove, a jet pump connected into the drill string and including a power nozzle, a throat, a diffuser, a pump inlet opening between the power nozzle and the throat and a pump outlet past the diffuser, the power nozzle having a nozzle inlet conveying a source of power fluid to the power nozzle to drive the jet pump and the pump inlet being open to a return flow path in pressure communication with the lower annulus, the jet pump being operable to reduce the fluid pressure in the return flow path, and a bypass port for fluid flow toward the drill bit and around the jet pump; providing a flow of drilling fluid to pass



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through the power nozzle inlet, the drill bit and the return flow path; operating the drill bit to extend the wellbore.

The preferred process for drilling an underground wellbore from the surface places the invention at sufficient depth to create the desired condition at the drill face and exposed rock formation. Power fluid actuates the jet pump to reduce bottomhole pressure while fluid is circulating at sufficient rate, which may be while the bit is drilling. The power fluid driven jet pump draws in the bottom hole return fluid, along with drill cuttings and entrained formation fluids, at reduced pressure and discharges the mixture above the packer at sufficient pressure to reach the earth surface. Check valves control reverse flow and maintain reduced pressure when drilling fluid is not circulating such as while making pipe connections or while tripping the pipe. The packer is operable to maintain the seal while operations occur that reduce fluid circulation pressure.

Reduced lower annulus fluid pressure must be ensured to achieve the objectives of reducing cost, reducing well flow impairment and evaluating formation fluid characteristics and flow capability.

#### BRIEF DESCRIPTION OF THE DRAWINGS

A further, detailed, description of the invention, briefly described above, will follow by reference to the following drawings of specific embodiments of the invention. These drawings depict only typical embodiments of the invention and are therefore not to be considered limiting of its scope. In the drawings:

Figure 1 is a schematic view illustrating an assembly according to the present invention.

Figure 2 is a longitudinal cross section through a pressure differential drilling tool according to the present invention.

Figure 3 is a sectional view along line 3 - 3 of the tool of Figure 2.

Figure 4 is a sectional view along line 4 - 4 of the tool of Figure 2.

Figure 5 is a longitudinal cross section through another pressure differential drilling tool according to the present invention.

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Figure 6A is a longitudinal cross section through another pressure differential drilling tool according to the present invention.

Figure 6B is a sectional view along line B-B of Figure 6A.

Figure 6C is a sectional view through an oil filled chamber useful in the tool of Figure 6A.

- 5 Figure 7 is a longitudinal cross section through another pressure differential drilling tool according to the present invention.

Figure 8 is a longitudinal cross section through another pressure differential drilling tool according to the present invention.

- 10 Figure 9 is a longitudinal cross section through another pressure differential drilling tool according to the present invention.

Figure 10 is a longitudinal cross section through another pressure differential drilling tool according to the present invention.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

- 15 Referring to Figure 1, a pressure differential drilling assembly and tool according to the present invention are shown.

- 20 A pressure differential drilling tool 10 according to the present invention includes a jet pump 12 and sliding packer 14. For use, drilling tool 10 is mounted in a drill string 16 passing into a wellbore 18 through a formation 19. Packer 14 is selected to create a seal between drill string 16 and the wellbore 18 such that a pressure differential can be set up in the annulus about the packer. To facilitate sealing of the packer, a stabilizer or centralizer 20 is mounted on the drill string. The drill string can be formed of, for example, drill pipe, tubing, coiled tubing or drill casing. The wellbore extends from surface 21 to bore bottom 22 and is lined with wellbore casing 23 at its upper end. The wellbore can be of any type that is bored using a drill string and wherein drilling fluid is returned to surface by circulation through the annulus 25 between the drill string and the wellbore wall such as conventional or slim hole sized wellbores. Wellbore 18 will generally be a vertical, deviated, directional or horizontal, conventional or slim hole sized wellbore of less than 36 inch diameter. A drill bit 26 such as,
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for example, a rotary drill bit or hammer bit, is attached onto drill string 16. The drill bit cuts into the formation at bore bottom 22 and advances the wellbore into the formation. Drill bit 26, in the illustrated embodiment, is driven to rotate and thereby cut into the formation by operation of a downhole motor 27 driven by drilling fluid. Alternately, the drill bit and drill  
5 string can be driven to rotate from surface. The drill string can also include measurement while drilling or other devices (not shown) for monitoring the drilling operation.

In a drilling operation, drilling fluid, for which flow is shown in Figure 1 by arrows, is pumped from a system of surface tanks or pits and pipes, generally shown as 28, by a pump 30, and injected into the inner bore 32 of drill string 16. The drilling fluid is injected at a  
10 sufficient rate and pressure to achieve proper performance in the wellbore and subsequently to achieve return fluid circulation to surface.

When the drilling fluid passing through the drill string bore 32 reaches jet pump 12, the fluid can pass through two separate paths. In particular, bypass ports 33 are provided about jet pump 12 so that a portion of the fluid, referred to herein as bit fluid, can flow therepast, while  
15 some fluid, referred to as power fluid, passes through a power nozzle 34 of jet pump 12, as will be described in more detail hereinafter. The bypass ports can be drilled ports as shown or other fluid conduit arrangements. In addition, the power fluid can pass with the bit fluid until it reaches the power nozzle, as shown, or other configurations can be used wherein the bit fluid is separated from the power fluid somewhere apart from the power nozzle and  
20 conveyed separately to the power nozzle.

The bit fluid continues through drill string 16 until it passes through motor 27 and out through nozzles in drill bit 26 into the space between the drill string and the wellbore, referred to herein as annulus 36. The drilling fluid then passes up the annulus towards surface 21. This fluid usually contains formation cuttings, created by action of the drill bit,  
25 and can contain formation fluids such as water or gas.

Using the tool of the present invention, the fluid, after passing through the drill bit, can pass up the annulus until it reaches packer 14. The slidable packer seals against fluid passage therepast through the annulus. Therefore, the fluid is diverted through jet pump 12. Jet pump 12 has a pump inlet 40 and a pump outlet 42. A fluid conduit 45 extends between power  
30 nozzle 34, pump inlet 40 and pump outlet 42. Drilling fluid can only flow to surface by passing through the jet pump via inlet 40 and outlet 42 as assisted by power fluid flowing

through power nozzle 34.

In an underbalanced drilling operation, the pressure of the drilling fluid in the lower annulus near the bore bottom must be less than the fluid pressure of the surrounding formation 19. According to the present invention, the power fluid portion of the drilling fluid activates the  
5 jet pump action to suck drilling fluid from the annulus below the packer reducing fluid pressure acting against the wellbore and the drill face below the packer.

To provide for control of the amount of fluid passing through power nozzle 34, preferably a fluid flow rate regulator 46 is provided in the drill string between the jet pump and the drill bit. In particular, fluid from surface is divided into two flow paths at the jet pump. The  
10 portion of the volume that will flow through each flow path is determined by how much flow resistance occurs in each path. The restriction through the power nozzle is very small so, without modification, a relatively small amount of fluid will go through the power nozzle. For a jet pump to work most effectively it must have a large amount of fluid passing through it. Therefore, for improved functioning and control of the jet pump, extra flow restriction is  
15 applied to the bit fluid to decrease the volume of fluid getting to the bit and increase the proportion of fluid passing through the power nozzle. A flow rate regulator 46 can be used in the flow path between the tool and the drill bit to limit flow to the bit to volumes sufficient for proper bit functioning, but not to exceed a predetermined value. Thus, it will be appreciated that the use of a flow rate regulator as shown will permit control of jet pump  
20 operation since an increase in the flow rate of drilling fluid from surface will directly affect the amount of fluid passing through the jet pump. A useful flow rate regulator is, for example, available from Baker Oil Tools known as the Model DSJ™ product no. 813-68.

One embodiment of tool 10 of the present invention is shown in greater detail in Figures 2 to  
25 4. The tool is inserted into a drill string 16 by upper and lower threaded connections 47, 48. The tool includes a jet pump 12 and a packer 14. Bypass ports 33 provide for fluid flow past the jet pump through bore 32 of the drill string. In the illustrated tool (Figures 3 and 4), five bypass ports are formed through the body defining the jet pump. However, it is to be understood that any number and configuration of ports is within the invention provided that  
30 fluid flow past the jet pump is provided without opening into any of the internal fluid passages of the jet pump.

Packer 14 is sealably disposed about the exterior surface 10a of the tool between pump inlet

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40 and pump outlet 42. While the tool has an outer diameter selected to pass through the wellbore, packer 14 is selected such that when it is in sealing position in the wellbore, it extends between the jet pump and the wellbore wall (not shown in Figures 2 to 4) and creates a seal therebetween. The seal prevents fluid flow between the jet pump and the wellbore wall past the packer. While some microscopic fluid flow past the packer may periodically occur, any detectable leakage must be avoided. Those skilled in the art will know methods for testing the seal integrity of a packer such as, for example, by monitoring drill string weight during a drilling operation using the tool.

The packer is mounted on the tool and is slidable along the wellbore while maintaining the seal. This is necessary to permit advancement of the drill string and jet pump as the drill bit extends the wellbore, while maintaining the seal. A packer that can withstand the movement along the wellbore and preferably repeated trips down and uphole is preferred. As an example, a packer having a reinforced and/or beveled outer edge can be used. Drilling of the underground formation is achieved by applying compressional force to the formation, via the drill bit, most often in combination with rotating the drill bit. The packer seal must withstand all movements of the drill string, if pressure underbalance is to be maintained. In order to advance the drill bit it is necessary to advance the drill string so the packer in this embodiment must be able to move longitudinal through the wellbore without losing its seal. In order to rotate the bit, it is necessary to either rotate the drill string or use a downhole motor and it is sometimes necessary to combine the two rotational methods. Thus, in many applications the packer must allow for rotational movement of the drill string. Such rotational movement may be accommodated at the packer-wellbore interface and/or preferably at the packer-tool interface. Cup type packers, of the type commonly available through petroleum industry suppliers such as Guiberson AVA (part no. 17786 for 7 inch casing), will accommodate, longitudinal and rotation movement under low loadings in terms of pressure, rotation and sliding. Modification of that packer or use of an alternative packer may be necessary as more severe loadings are demanded for specific well drilling situations. In some applications, it may be necessary or desirable to use a plurality of packers in series.

A cup-type packer is shown in Figure 2. Such a packer has a base 49 and a circumferential wall 50 extending therefrom. During use, pressures above the packer are intended to be greater than pressures below the packer. Therefore, the packer is mounted such that wall 50 extends upwardly from the base to its outer edge 50a. The packer is formed of deformable,

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elastomeric material such as, for example, rubber or polyurethane cast about an internal support 51 of rigid material such as steel or aluminum. Outer edge 50a is beveled to facilitate movement along the wellbore wall and in particular through casing connections when being pulled towards surface. A seal 52 such as an O-ring is carried on the base to effect a seal  
5 between the jet pump and the packer. The packer is mounted on drill string by use of set screws 53. The set screws pass through the packer and engage the tool outer surface preventing the packer from moving relative to the jet pump. Where it is desirable to permit rotation of the packer about the jet pump body, the mounting can be achieved in other ways. In one embodiment, the base of the packer is mounted between a pair of shoulders on the  
10 surface of the jet pump. The shoulders can be integral with the jet pump body or can be formed by rings mounted about the jet pump.

While the illustrated packer has been described, any packer that is capable of sealing between the jet pump and the wellbore while being slidable along the wellbore can be used.

Jet pump 12 includes a power nozzle 34, a pump inlet 40 and a pump outlet 42. A fluid  
15 conduit 45 extends between power nozzle 34, pump inlet 40 and pump outlet 42 and, thereby, open communication is provided between nozzle 34, inlet 40 and outlet 42. Conduit 45 is shaped to define the standard parts of a jet pump including a throat 54 and a diffuser 56. While a central-type power nozzle, as illustrated, is preferred, alternately a peripheral or annular-type power nozzle can be used. While only one each of the inlet and outlet are  
20 shown, more than one of each can be provided, as desired.

Inlet 40, outlet 42 and throat 54 are sized to permit passage therethrough of drill cuttings. Preferably, inlet 40 has a diameter that is reduced from that of the throat such that the inlet acts as a screen against oversized debris entering the jet pump where it may become jammed in the throat. Any materials that bridge the inlet can be cleared easily when the tool is  
25 brought to surface and/or may fall away from the inlet when the fluid circulation is stopped.

Jet pump 12 can be formed as a single unit or, to facilitate manufacture and repair it is formed of a plurality of parts connected together by, for example, welding and/or threaded connections. In particular, it is preferred that the power nozzle be removable since it is prone to fluid erosion and may need to be changed to select for size depending on the well  
30 conditions and depth. As such, in one embodiment power nozzle 34 is connected into the tool by threads 35. Preferably, a removable top plug 57 provides access to conduit 45 and

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can be replaced since this wall portion of the conduit will also be prone to erosion.

The tool is formed of materials, and can have coatings, selected to reduce the effects of erosion. In addition, rough and/or sharp edges should be avoided as much as possible to reduce fluid turbulence and frictional pressure losses. In addition or alternately, additives can  
5 be added to the drilling fluid that reduce turbulent friction pressure losses. Common additives for this purpose are, for example, hydrolyzed polyacrylamides, xanthan gums and hydroxyethylcellulose polymers.

In operation, drilling fluid from surface passes through bore 32 of drill string and through bypass ports 33. Once out of ports 33, a portion of the drilling fluid, referred to herein as the  
10 bit fluid, continues down the drill string towards the bit. A second portion of the drilling fluid, referred to herein as the power fluid, passes through power nozzle 34. The power fluid exits the power nozzle of the jet pump, enters throat 54, passes through the tapered diffuser 56 of the jet pump and exits the jet pump via pump outlet 42. Because of the seal in the annulus created by packer 14, the power fluid next flows toward the surface via the annulus  
15 between the drill string and the cased wellbore.

When power fluid flows through an appropriately sized jet pump, an area of reduced pressure is created in the region between the nozzle and the throat by means of a Venturi effect. External fluid is drawn into the area of Venturi reduced pressure via inlet 40. The external fluid then passes through the jet pump where it is mixed with the power fluid and discharged  
20 from the jet pump at high pressure through pump outlet 42.

The external fluid is the bit fluid that has passed the bit and includes drill cuttings and formation fluids generated by the drill bit. The external fluid is in the annulus below the packer. The pressure in the annulus is a combination of the pressure at the top of the annulus plus the pressure exerted by the column of fluid in the annulus. The suction inlet 40 is  
25 located at the top of this annulus so when pressure is reduced at the suction inlet, the pressure at all points in the lower annulus will be reduced accordingly. When power fluid is supplied to the jet pump at sufficient rate and pressure, the resulting pressure in the annulus between the drillstring and the wellbore can be made lower than the pressure of fluids in the formation and such fluids will then flow into the annulus. This is the condition for what is referred to as  
30 "underbalanced drilling" when drilling is simultaneously occurring.

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During periods of reduced or interrupted fluid circulation, it may be necessary to maintain underbalanced conditions wherein the region in the annulus below the packer is at a lower fluid pressure than those above the packer and within the drill string. Thus, referring to Figure 5, in one embodiment, the tool of the present invention includes at least one valve for preventing fluid flow in a reverse direction through the jet pump. In particular, a ball 70 is disposed in diffuser portion 56 and is selected to seat in throat 54 to seal against reverse flow through the throat of the jet pump. When tool 10 is in use and fluid is flowing upwardly through the throat portion, ball 70 is carried in the flow and creates no seal. In particular, outlet 42 is formed to retain ball 70 within diffuser portion 56 without blocking fluid flow through the outlet. In particular, outlet port 42 is formed as a slot or an oval and the ball is wider than the narrowest portion of the opening. Other means for maintaining the ball in the diffuser can be used as desired.

To prevent reverse flow through the nozzle, a spring-actuated reverse flow ball-type check valve 72 is provided at the power nozzle inlet. Valve 72 includes a spring 74 that adds a back pressure function to the valve. Normally, the spring forces ball 76 into sealing relation against seat 78. The force of spring 74 is selected such that fluid pressures below a selected level will be unable to unseat ball 76. Thus, when drilling fluid is below the selected pressure, the drill string will operate in a standard mode without action of the jet pump and the jet pump will only begin to operate when the fluid pressure reaches a predetermined level sufficient to overcome the compression in spring 74. This is particularly, useful during drilling start-up where it is preferred to drive operation of the drill bit before the jet pump. In addition, when drilling is stopped, valve 72 prevents passage of the drill pipe fluid into the upper and lower annulus.

An elastomeric cup seal 80 is mounted about nozzle 34 and is sized to prevent reverse flow from the throat through inlet 40. In particular, cup seal 80 is deformable such that during normal operation flow through inlet 40 can pass into throat 54. However, when the jet pump is not operating any fluids flowing back through inlet 40 act on cup seal 80 to seal off flow through the inlet.

Valves can be provided at additional or alternate positions within the jet pump to prevent reverse flow and loss of differential pressure or to control fluid supply sequence. For



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example, instead of a ball valve in the diffuser, a valve can be positioned to seal off the pump inlet or the pump outlet. However, generally there is more room in the diffuser for such a valve. A valve in the suction inlet can be used to prevent overpressuring the annulus while the jet pump is being brought up to the appropriate rate. Valves can also be added in bit fluid  
5 paths. In some embodiments, valves are positioned for safety and well control to reduce passage of high pressure fluid up hole, for example, in a well blow out situation.

Various forms of valves are useful. Ball valves have been proven particularly useful in oilfield, vertical orientation applications. Spring actuated valves may be needed in non-  
10 vertical orientations. Plunger, flapper and sliding sleeve valves are also useful in certain applications. The selection of a suitable valve for various purposes is within the art.

As noted previously, a fluid flow rate regulator can be provided in the drill pipe below the tool to regulate fluid flow to the drill bit. In one embodiment, a fluid flow rate regulator can  
15 be provided to regulate fluid flow through the power nozzle where it is necessary to be able to vary flow through the bit without affecting the lift created by the power nozzle.

Referring to Figure 6, another tool according to the present invention is shown in drilling configuration wherein the jet pump would be operating to create lift in the lower annulus.  
20 The tool 100 has a body 111 defining a jet pump 112 and, mounted about the body, a compound packer 114 including five sealing elements 115. Jet pump 112 includes a power nozzle 134, three pump inlets 140, three pump outlets 142, a throat 154 and a diffuser 156.

Five bypass ports 133 extend through body 111. Bypass ports 133 at their lower end are open  
25 to a chamber 158. Chamber 158 is in communication with power nozzle inlet 134a and the lower drill string bore 132 through a port 159. Thus, any fluid passing out of bypass ports 133 into chamber 158 divides such that a portion passes through power nozzle 134 and a portion passes toward the drill bit.

30 A ball 170 is positioned in the diffuser and creates a reverse flow check valve. The ball is shown in an open position, which is the position during normal fluid circulation.

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A sliding sleeve valve 172 is provided to seal passage of fluid through the bypass valves when the circulation of drilling fluid is stopped. In particular, nozzle 134 and throat 154 are carried on sleeve 172, which is slidable in a bore 174 in body 111. Sleeve 172 is slidable between an open position wherein fluid can pass out of chamber 158 and a closed position  
5 wherein access from chamber 158 to power nozzle 134 and port 159 is sealed off. Upwards sliding movement of sleeve 172 is limited by shoulder 175 in bore 174 and downwards movement is limited by seat 176. O-rings 178 are positioned between sleeve 172 and bore 174 to prevent fluid flow therethrough while permitting sliding therebetween.

10 The sleeve has formed thereon a shoulder 180 sized and positioned to be acted on by circulation fluid pressure (hydrostatic pressure and pump pressure) to drive sleeve into the open position. When the pump is stopped, the ball 170 seats in the diffuser due to gravity. Since the sleeve 172 is connected to and moves with diffuser 156, setting of ball 170 in  
15 diffuser causes sleeve 172 to seat due to a combination of higher upper annular hydrostatic pressure and gravity acting on the ball and sleeve assembly. Inertia, such as when the drill string is moved upward in the process of making or breaking a connection or tripping out the drill string, will also cause the sleeve 172 to seat.

As noted hereinbefore, packer 114 includes five sealing elements 115. Each element is  
20 formed of a durable elastomeric material such as rubber or polyurethane. The outer diameter of each element in uncompressed form is selected to be greater than the inner diameter of wellbore or casing 123, (shown in phantom,) in which it is to be used. As such, the packer acts as an interference fit packer.

25 Packer elements 115 are held in side by side relation between rings 190. An oil-filled bearing 192 provides for rotation of the packer about body 111. Bearing 192 includes a plurality of ball bearings 193 in grooves 194 in the tool body. An oil-filled bearing chamber is sealed by sealing elements 197 in rings 190. The bearing restricts the packer against longitudinal movement along the body. In one embodiment shown in Figure 6C, one of the bypass ports  
30 198 is sealed off by pistons 199 at either end thereof and is filled with oil in communication with the oil-filled chamber of bearing 192. Fluid pressure acting against the pistons acts to adjust for pressure differences between the oil in the bearing and the external fluid pressure to

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prevent drilling fluid entry to the bearing area such that oil lubrication is maintained to minimize bearing friction and wear.

Referring to Figure 7, another tool according to the present invention is shown in drilling configuration wherein the jet pump is operating to create lift in the lower annulus. The tool 5 200 includes a body 211 defining a jet pump 212 and, mounted about the body, two cup packers 214. Tool 200 includes two reverse flow check valves. In particular, a ball 270 is disposed in the inlet to jet pump nozzle 234. A rod 272 extends across the nozzle inlet to prevent the ball from sealing off the nozzle. When flow reverses, ball 270 seats against valve 10 seat 276 to prevent reverse flow through the nozzle.

The tool's other reverse flow check valve is positioned in pump inlet 240. The check valve includes a ball 290 and seat 292. Ball 290 is positioned in an opening with a slot 293 formed at the inner end. Slot 293 is narrower than the diameter of ball 290 such that the ball cannot 15 pass therethrough to seal against the throat 254.

In a drilling operation where there is a low volume of drilling fluid circulating, it may be advantageous to reverse circulation of drilling fluid over those systems discussed hereinbefore such that it flows downhole through the annulus to return up through the bore of 20 the drill string. The tool of the present invention can be used to create underbalanced conditions in such a drilling operation. In particular, referring to Figure 8, a pressure differential drilling tool 300 is shown that is useful for operating with a circulation of drilling fluid passing down hole through the annulus between the drill string and the borehole and returning, containing drill cuttings, through the drill string bore.

25 Tool 300 is connectable at its ends into a drill string 16 and includes a jet pump 312 and a pair of sliding packers 314. Jet pump 312 includes a throat 354 and a diffuser 356. Fluid acted on by jet pump enters through a pump inlet 340 and exits through a pump outlet 342 above the diffuser.

30 In a drilling operation, drilling fluid, for which flow is shown by the arrows, is pumped down the annulus and enters the tool through an inlet port 318. Continued flow through the annulus is prevented by packers 314. After entering through port 318, drilling fluid can pass through

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channel 320 and out into the annulus below the packers through a lower annulus outlet port having a fluid flow restrictor 323 mounted therein. Fluid flow restrictor 323 limits the volume of fluid that can flow therepast. Thus, a pressure differential can be established about flow restrictor 323 wherein the pressure in the annulus is lower than the pressure in channel  
5 320. Fluid passing through channel 320 and flow restrictor 323, referred to herein as bit fluid, flows down the annulus, passes through the drill bit and returns up through the drill string bore.

A portion of the drilling fluid entering through inlet port 318 passes through power nozzle  
10 334 of the jet pump. This portion of the drilling fluid is referred to herein as power fluid. This power fluid draws fluid through port 340, from bore 336 of the tool and through the bore of the drill string and through the nozzles of the drill bit to create lift and reduce the pressure of the fluid in the drill string bore and in the annulus between the drill string and the formation below flow restrictor 323 of the tool.

15 Another tool 400 according to the present invention is shown in Figure 9. Tool 400 is useful in drilling operations where, after the drilling operation is complete, it is desirable to leave the drill string downhole and to pump produced fluids therethrough. Tool 400 can act to both create underbalance condition in the drilling fluid during a drilling operation and to create lift  
20 for produced fluids.

Tool 400 is connectable at its ends into a drill string and includes a jet pump 412 and a pair of sliding packers 414. Jet pump 412 includes a nozzle 434, a throat 454 and a diffuser 456. Fluid acted on by jet pump enters through a pump inlet conduit 440 and exits through a pump  
25 outlet 442 above the diffuser.

In a drilling operation, drilling fluid, for which flow is shown by arrows, is pumped down the annulus and enters the tool through an inlet port 418. Continued flow through the annulus is prevented by packers 414. After entering through port 418, drilling fluid can pass through  
30 bore 420 and into the inner bore of the drill string. This drilling fluid, termed herein as bit fluid, flows down through the drill bit and returns up through the annulus between the borehole wall and the drill string until it reaches packers 414. At this point, the drilling fluid

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can pass into the tool via pump inlet conduit 440. Pump inlet conduit extends from port below the packer to open between nozzle 434 and throat 454.

A portion of the drilling fluid, referred to herein as power fluid, passing through inlet port 418 passes through power nozzle 434 of the jet pump. This power fluid acts on fluid returning through the annulus and draws fluid through a pump inlet conduit 440. In this way, lift is created in the drilling fluid and the pressure of the fluid in the annulus below the packer is reduced, or underbalanced, relative to the drilling fluid pressure in the annulus above the packer and in the drill string bore.

10

When it is desired to cease drilling and begin producing the formation fluids, the drill bit is actuated, as is known, to close off all ports therethrough such that no fluid will pass through bore 420. Thus, all fluid pumped downhole through the annulus will pass through port 418 and power nozzle 434. In the same way as the drilling operation, fluid passing through power nozzle 434 will create a vacuum in pump inlet conduit 440 and will tend to lift any fluids, including any formation fluids located in the annulus below the packer.

In one embodiment, the jet pump is included in a body that is releasably mounted within the drill string and is retrievable therethrough without removing the drill string. In particular, referring to Figure 10, a pressure differential drilling tool 500 includes a retrievable body 505 sized to fit into and be positionable in a section of drill pipe 516 that is connected into the drill string. Retrievable body 505 includes a jet pump 512 including a power nozzle 534, a throat 554 and a diffuser 556, a bypass port 533, a pump inlet 540 and a pump outlet 542. Deformable seals 543 are positioned about body 505 to create seals between the body and the drill pipe section about inlet 540 and outlet 542. The retrievable body has mounted thereon at least one retractable latch 531 (two are shown) for engagement with an annular profile 532 in the drill pipe. Latch 531, when engaged in profile 532, holds the tool body in position in the section of drill pipe. Drill pipe section 516 has disposed thereabout a packer 514. A lower port 546 is positioned below the packer and an upper port 548 is positioned above the packer. Ports 546, 548 each extend through the wall of the drill pipe section and open into lower and upper annular recesses 550, 551, respectively, formed on the inner surface of the drill pipe. When latches 531 are latched into profile 532, inlet 540 and outlet 542 align with and open into recesses 550, 551, respectively.

Latches 531 are common wireline latches. In particular, the latches pivot about pin connections 559 and are biased outwardly by springs 560 such that, during installation, when the latches ride into the profile, the latches will spring out into engagement with the profile.

5 In the engaged position, rear extensions 561 protrude through slots 562 into upper bore 563 of body 505. To retrieve body 505 from drill pipe section 516, a fishing tool (not shown) is tripped downhole to engage fishing neck 565. The fishing tool also includes a spear portion that is sized to fit down into bore 563 and push against rear extensions 561. This action causes latches 531 to rotate about pin connections 559 and against the force in springs 560 to

10 retract latches out of engagement with profile 532.

The jet pump body can be retrievable by means of a wireline, coiled tubing or other pulling means. In other tool embodiments, not shown, retrieval can be by circulating fluid to dislodge the body from its mounting position in the drill string. While a retrievable

15 embodiment is not preferred, it is sometimes useful to quickly retrieve the jet pump for unplugging ports, for repair or for changing nozzle or throat sizes. If a retrievable jet pump is desired and it is also desirable to maintain fluid pressure differential about the packer, it may be necessary to provide a valve in the drill pipe to block open ports in the drill pipe remaining after removal of a retrievable jet pump.

20 In order to achieve underbalance, a pressure reduction must be achieved at the bottom of the wellbore. The pressure reduction that is required for any particular application can be determined by consideration of, for example, minimum drilling requirements, jet pump performance calculations, pipe circulating pressure friction loss calculations, field fluid

25 properties and variations at the drill location.

For example, in one preferred embodiment where the power fluid is pumped down the drill pipe with the objective of underbalance, as a first step in using the tool of the present invention input parameters are considered. As will be appreciated, input parameters in conventional drilling are, for example, hole size; maximum drill depth; largest useable drill

30 pipe diameter; drilling fluid type and properties; minimum fluid circulation rate through the drill bit; drill string components; drilling rig pump limitations of pressure, horsepower and flow rate; and existing pressure of fluids in the formation to be drilled.

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Next, the desired bottom hole pressure is selected to create the desired underbalance or reduced pressure condition. This is done by calculating the height of the column of drilling fluid above the bit that would create the desired bottom hole pressure and convert this height into well depth. This depth is used as the minimum depth, at the end of drilling operations, at which the jet pump drilling tool of the present invention would be installed. This depth also represents the recommended minimum depth to which casing should be run in a wellbore planned for continuous underbalanced drilling, since preferably, the packer of the tool acts against casing.

To select an appropriate size of jet pump for achieving the underbalance, estimations are made concerning jet pump suction pressure, jet pump power nozzle diameter and jet pump throat diameter. Calculations are then made to determine the power fluid flow rate that is required for the jet pump to lift fluid at a rate equal to the minimum fluid circulation rate through the drill bit. If the pressure exceeds the pressure rating acceptable for the rig operation, then recalculate with larger nozzle sizes. Calculate the friction pressures with those rates and iterate to determine workable limits for pressure in the system. Many different calculation procedures can be used to arrive at an optimum solution. Computer aided selection is the most practical as this facilitates trying a number of different values for each parameter.

The pump performance characteristics can be taken from the Petroleum Engineering Handbook, which has typical performance normalized from tests using oil or water as the power fluid. To obtain more accurate performance characteristics it may be necessary to put an actual power fluid through a pump mounted at surface and analyze function by use of pressure gauges and flow meters. Actual testing to optimize the pump parameters is preferred where: non-Newtonian drilling fluids are used; friction reducing chemicals are used; or experimental pump configurations are employed.

Once the operating parameters are established it will be necessary to calculate the pressure losses for the bit fluid through the balance of the flow path. If the calculated pressure losses from the power nozzle to the pump inlet are less via the flow path through the bit than via the flow path through the jet pump nozzle, then extra flow restriction must be installed such that the pressure loss is equal.

Once the tool according to the present invention is deployed in the wellbore, the circulating

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- friction losses at various rates should be compared to the theoretical. If there are differences, the equations should be calibrated accordingly and the system performance recalculated. Downhole pressure information can also be used for recalibration. The differential pressure acting on the cross sectional area of the packer annulus will create a downward force that is
- 5 accurately reflected by the change in tension held at surface as observed by a weight indicating device. The difference between the initial static weight and the weight during fluid circulation will therefore reflect the pressure reduction achieved by the jet pump. Programmable logic controllers can be used to ensure the surface pump rates, surface pump pressures, and back pressure on the circulating system are within the proper balance.
- 10 It will be apparent that many other changes may be made to the illustrative embodiments, while falling within the scope of the invention and it is intended that all such changes be covered by the claims appended hereto.



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The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

- 5 1. A pressure differential drilling tool for reducing pressure in the annulus between a drill string and a wellbore in a drilling zone, the pressure differential drilling tool comprising: (a) a jet pump including a power nozzle having a nozzle inlet, a pump inlet, a pump outlet and a drilling fluid conduit extending between the pump inlet and the pump outlet and in communication with the power nozzle, the jet pump being  
10 connectable into the drill string such that the power nozzle inlet is open to a power fluid flow path providing a source of power fluid to the power nozzle to drive the jet pump and the pump inlet is open to a return flow path from below the jet pump, the jet pump being driveable to reduce pressure of fluid in the return flow path (b) a bypass port for fluid flow downwardly and around the jet pump and (c) a wellbore  
15 pack off seal positioned about the jet pump and operable to create a seal in the annulus preventing fluid communication between a high pressure region in the annulus and a low pressure region in the annulus and being moveable with the jet pump, while in operation, through the wellbore.
2. The pressure differential drilling tool as defined in claim 1 further comprising a valve  
20 to prevent reverse flow through the pump inlet.
3. The pressure differential drilling tool as defined in claim 1 further comprising a valve to prevent reverse flow through the power nozzle.
4. The pressure differential drilling tool as defined in claim 3 wherein the valve is biased to remain closed until fluid pressure at the power nozzle inlet is at a selected level.
- 25 5. The pressure differential drilling tool as defined in claim 1 further comprising a valve to prevent reverse flow through the pump outlet.
6. The pressure differential drilling tool as defined in claim 1 further comprising a lubricated bearing between the wellbore pack off seal and the jet pump.
7. A pressure differential drilling assembly for reducing fluid pressure in an annulus  
30 between a drill string and a wellbore in a drilling zone, the drill string including an

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inner bore for conducting drilling fluid therethrough, the pressure differential drilling assembly comprising:

... a drill bit for removing formation cuttings from the bore bottom and connected at a distal end of the drill string;

5           a wellbore pack off seal for creating a seal against drilling fluid flow therepast through the annulus about the drill string and defining a lower annulus therebelow and an upper annulus thereabove;

10           a jet pump connected into the drill string and including a power nozzle, a throat, a diffuser, a pump inlet opening between the power nozzle and the throat and a pump outlet past the diffuser, the power nozzle having an nozzle inlet open to a power fluid flow path for providing a source of power fluid to the power nozzle to drive the jet pump and the pump inlet being open to a return flow path in pressure communication with the lower annulus, the jet pump being operable to reduce the fluid pressure in the return flow path; and

15           a bypass port for fluid flow toward the drill bit and around the jet pump.

8.       The pressure differential drilling assembly as defined in claim 7 further comprising a valve to prevent reverse flow through the pump inlet.

9.       The pressure differential drilling assembly as defined in claim 7 further comprising a valve to prevent reverse flow through the power nozzle.

20    10.    The pressure differential drilling assembly as defined in claim 9 wherein the valve is biased to remain closed until fluid pressure at the power nozzle inlet is at a selected level.

11.    The pressure differential drilling assembly as defined in claim 7 further comprising a valve to prevent reverse flow through the pump outlet.

25    12.    The pressure differential drilling assembly as defined in claim 7 further comprising a fluid flow regulator disposed between the jet pump and the drill bit for regulating the flow of fluid toward the drill bit.

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13. The pressure differential drilling assembly as defined in claim 7 wherein power fluid flow path is the inner bore of the drill string and the pump inlet is open to the lower annulus and the pump outlet is open to the upper annulus.
14. The pressure differential drilling assembly as defined in claim 7 wherein the jet pump  
5 is carried on a retrievable body, moveable through the inner bore of the drill string and mountable within the drill string in a operable position and the packer is disposed about the drill string adjacent the operable position of the jet pump body.
15. The pressure differential drilling assembly as defined in claim 7 wherein the well pack off seal is mounted to the tool by an oil-filled bearing.
- 10 16. A process for drilling a wellbore through an underground formation using a drill string including an inner bore for conducting drilling fluid therethrough and creating a reduced fluid pressure in an annulus between the drill string and the wellbore in the drilling zone, the process comprising:  
  
providing a pressure differential drilling assembly including a drill bit for  
15 removing formation cuttings from the bore bottom and connected at a distal end of the drill string; a wellbore pack off seal for creating a seal against drilling fluid flow therepast through the annulus about the drill string and defining a lower annulus therebelow and an upper annulus thereabove; a jet pump connected into the drill string and including a power nozzle, a throat, a diffuser, a pump inlet opening  
20 between the power nozzle and the throat and a pump outlet past the diffuser, the power nozzle having an nozzle inlet conveying a source of power fluid to the power nozzle to drive the jet pump and the pump inlet being open to a return flow path in pressure communication with the lower annulus, the jet pump being operable to reduce the fluid pressure in the return flow path; and a bypass port for fluid flow  
25 toward the drill bit and around the jet pump;  
  
providing a flow of drilling fluid to pass through the power nozzle inlet, the drill bit and the return flow path;  
  
operating the drill bit to extend the wellbore.





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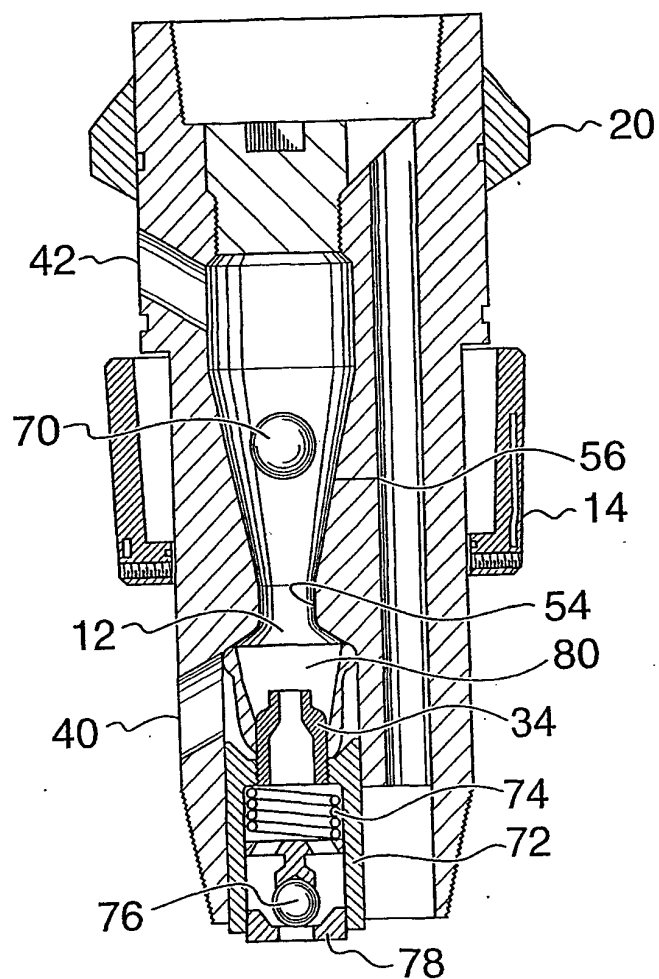
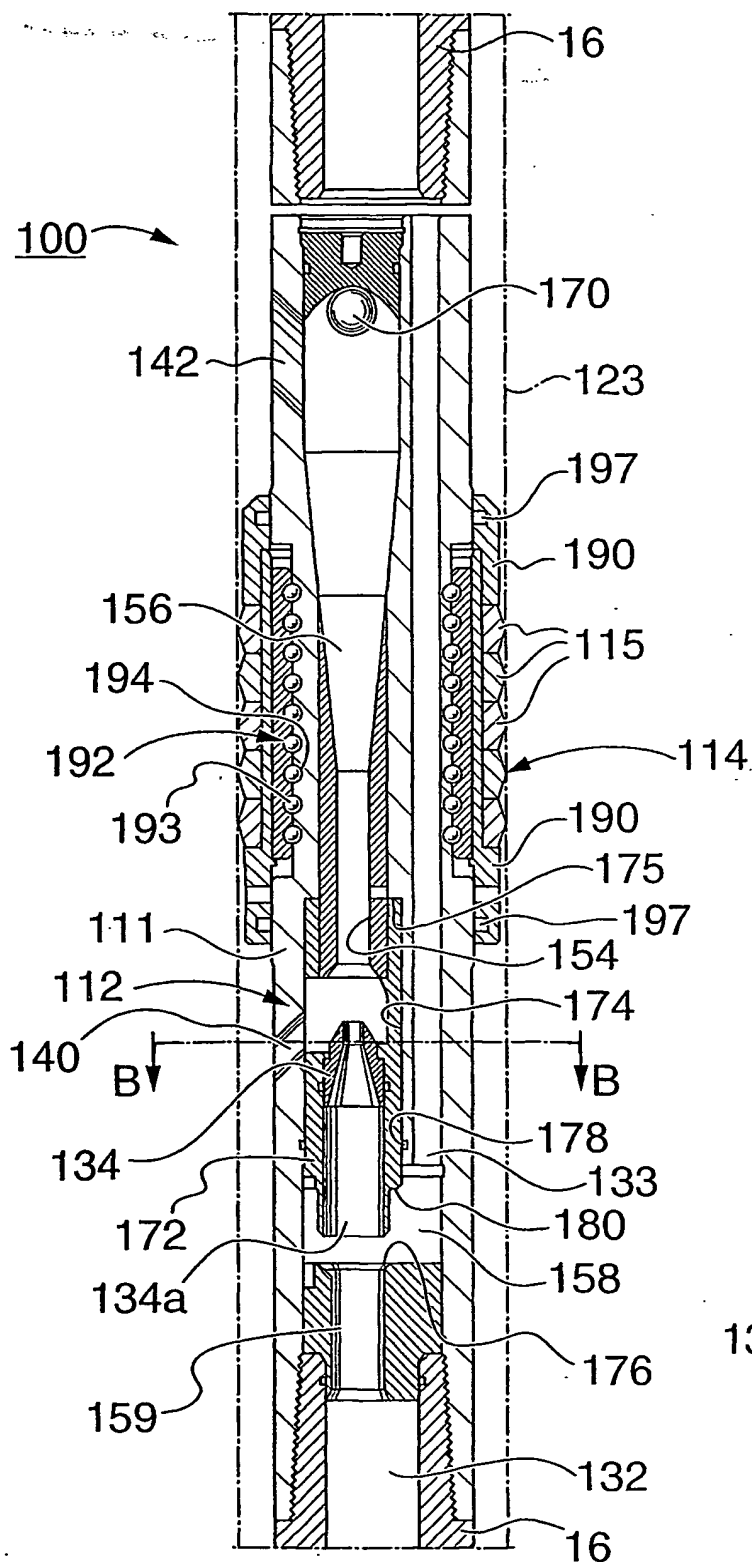
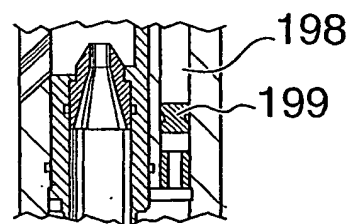


FIG. 5

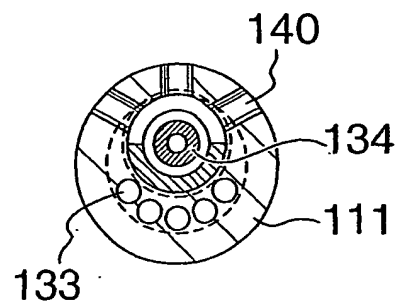
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**FIG. 6A**



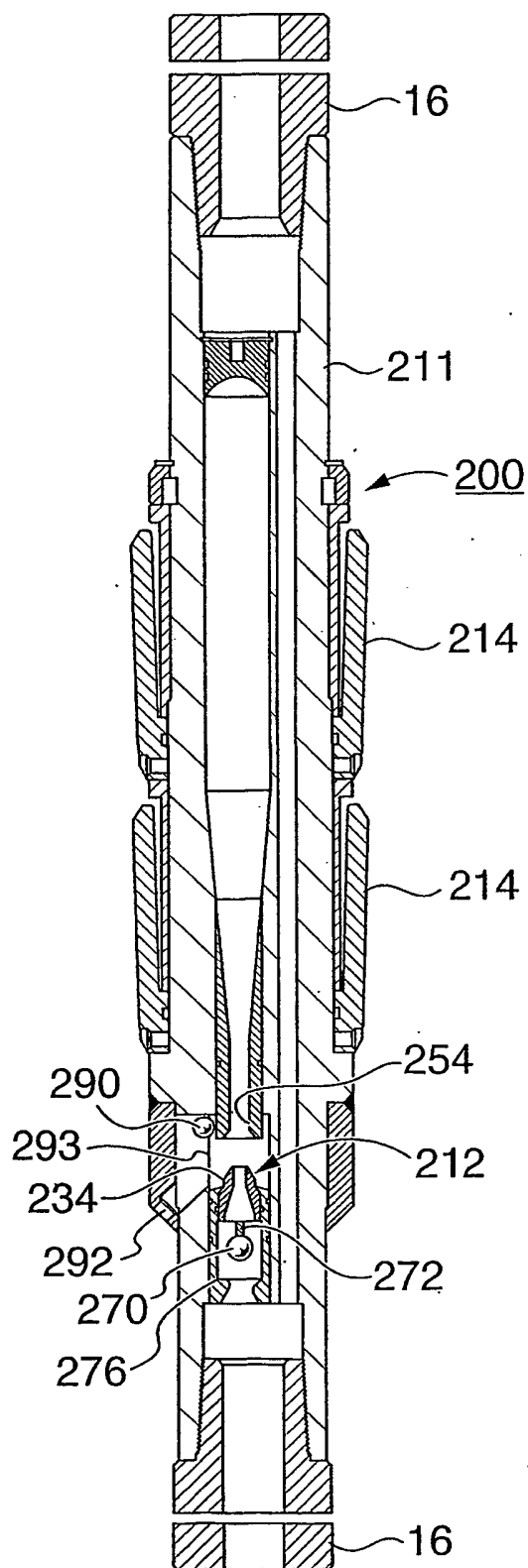
**FIG. 6C**



**FIG. 6B**

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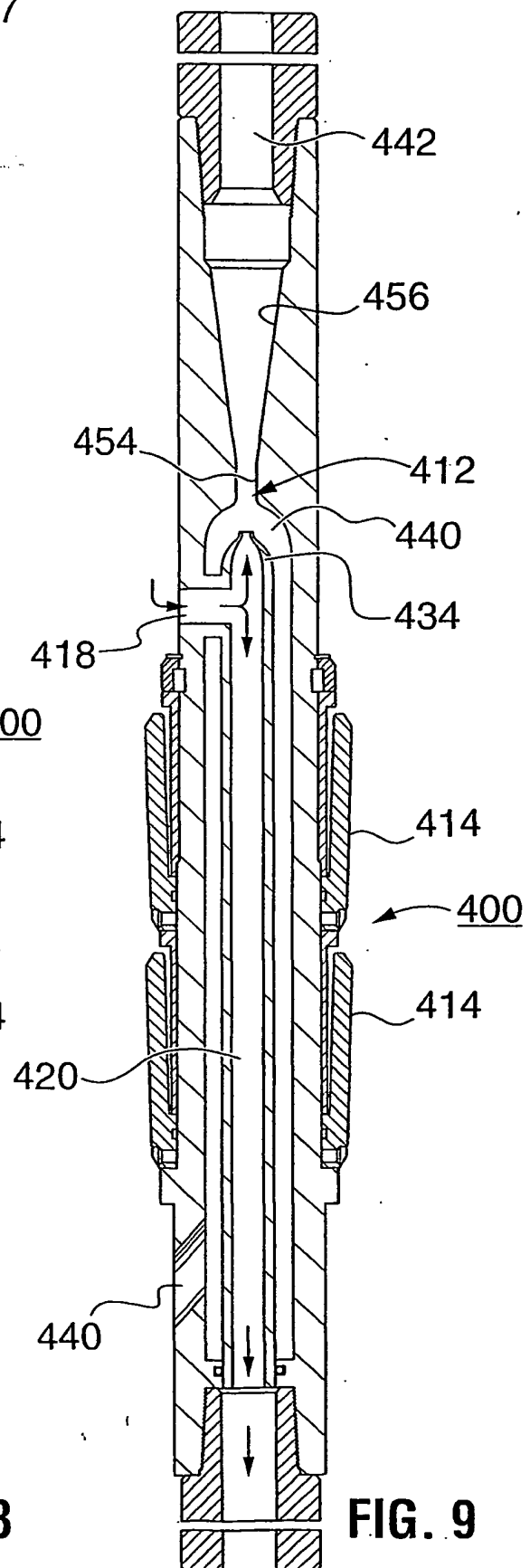
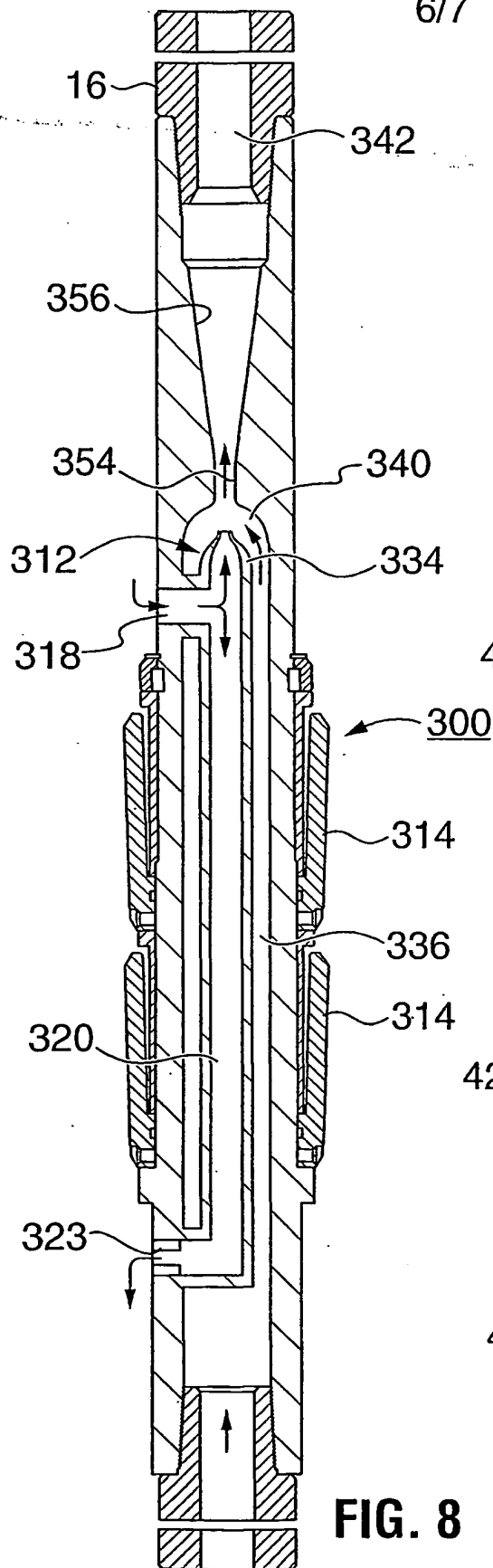
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**FIG. 7**



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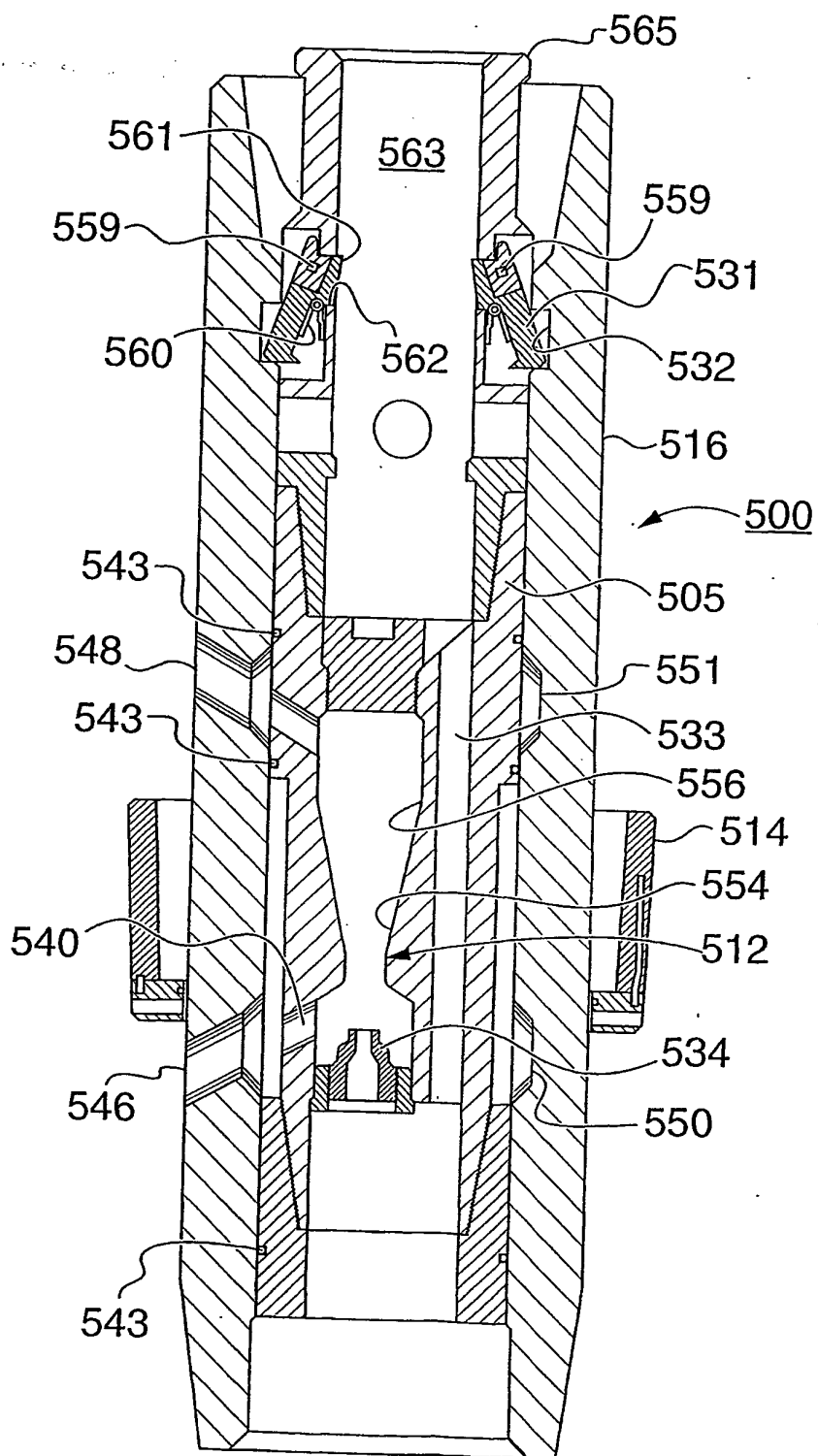


FIG. 10

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## INTERNATIONAL SEARCH REPORT

International Application No

PCT/CA 01/01134

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 E21B21/08 E21B21/10 E21B21/00

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the International search (name of data base and, where practical, search terms used)

EPO-Internal

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2 946 565 A (WILLIAMS PHILIP S) 26 July 1960 (1960-07-26) column 1, line 18 - line 28	1,7,12, 13,16
Y	column 2, line 30 - column 3, line 7; figure 1	2-6, 8-11,14, 15
Y	US 2 812 723 A (COBERLY CLARENCE J) 12 November 1957 (1957-11-12) column 1, line 68 - column 2, line 5 column 3, line 14 - line 25; figure 2	2-5, 8-11,14
Y	US 4 630 691 A (HOOPER DAVID W) 23 December 1986 (1986-12-23) column 10, line 51 - line 60; figure 10 -/-	6,15

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

22 November 2001

Date of mailing of the international search report

29/11/2001

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# INTERNATIONAL SEARCH REPORT

International Application No  
PCT/CA 01/01134

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/CA 01/01134

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